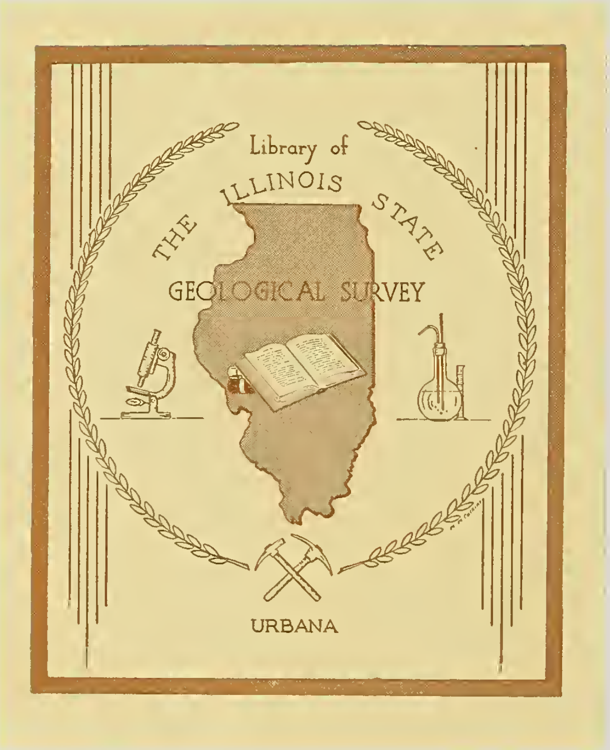

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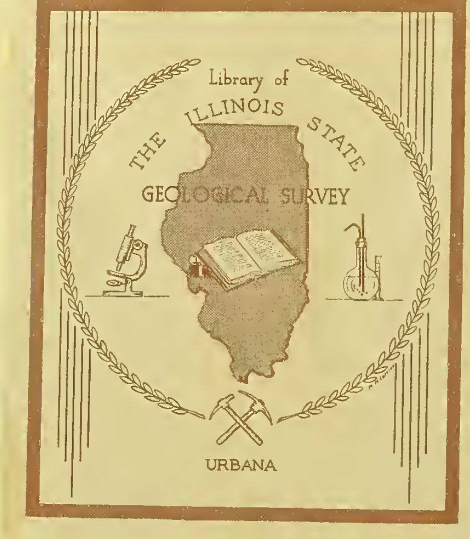

EFFECTS OF WASTE EFFLUENTS ON THE PLASTICITY OF EARTH MATERIALS

W. Arthur White and M. Katherine Kyriazis

INTRODUCTION

Contamination of his environment is one of man's most serious problems. Pollution of the atmosphere, streams, and lakes has received much attention in recent years, but an equally harmful form of contamination, the pollution of the earth's surficial materials, is less apparent and has received comparatively little consideration.

Effluents from septic tanks, landfills, refuse dumps, or waste disposal ponds contain chemical substances that permeate the surface materials and actually change their physical condition. As earth materials must support structures such as buildings, dams, and road beds for highways and railroads, such changes hold a potential danger.

For example, a slope might have sufficient stability in its natural state to support a residential development. After houses have been built and occupied, effluents from the septic tanks of the residences could permeate the earth of the slope to the extent that the clay materials, over an indeterminate period of years, would alter physically and chemically. The chemical attractive forces between the clay mineral crystals are weakened and the repulsive forces strengthened, resulting in the impairment of the structural strength of the material to the point where it will flow when disturbed. Under certain topographic and weather conditions, the sensitized clay may react to vibrations as diverse as earth tremors or those set up by passing trucks and may start to slide. The movement could be imperceptible or it could reach the dimensions of a landslide that would result in severe property damage, injury, or even loss of life.

Merriam (1960, p. 150) attributed the Portuguese Bend landslide near Los Angeles to the water from the cesspools of 150 houses. Söderblom (1966a,

p. 2) reported that chemicals dissolved from a waste dump by rainwater filtered through a normal clay and changed it to a "quick" clay in less than 20 years. A quick clay is stable until disturbed; it then becomes fluid and flows as a viscous liquid. A second report by Söderblom (1966b, p. 10) pointed out that, in the vicinity of a railroad station in northern Sweden, the normal clay on which a waste dump was located became quick in three years because of phosphates leached from the wastes.

The Illinois State Geological Survey has been investigating the effects of various materials found in waste effluents on the plastic properties of clay minerals. The first phase of the study (White and Bremser, 1966) demonstrated that soap, detergent, and water softener did affect the plasticity of clay minerals less than 2 microns in size. The second phase of the work, reported here, dealt with the changes effected in the plastic properties of five natural clays, each containing one or more minerals, by additions of a soap, nine detergents, two water softeners, a starch, and a fabric softener.

OCCURRENCE AND CHARACTER OF CLAY MATERIALS

The unconsolidated earth materials of Illinois occur in layers that were deposited at various times during the Pleistocene Epoch. They lie on an older (pre-Pleistocene) bedrock surface, which had been shaped by erosion into hills and valleys before these materials were deposited. No layer necessarily has the same geographic distribution as those above or below it (fig. 1). The surface of several of these layers was sculptured by erosion before the layer above was deposited. The layers differ in thickness and the thickness of any layer may vary from one geographic location to another. Loess, till, and lake clay layers all contain clay minerals. Sand and gravel have negligible amount

The problems of building dams, roads, tunnels, and foundations of large buildings in, on, through, and with earth materials containing clay minerals are well known to engineering geologists and geological and civil engineers. Instability of slopes, shrinking and swelling of the materials under foundations, and plastic flow of clay materials from beneath structures are known to depend on the kinds and abundance of clay minerals present in the earth. The common clay minerals are illite, kaolinite, chlorite, montmorillonite, and mixed-layer clay minerals, all of which occur in Illinois. The clay mineralogy of one layer of earth material may be the same throughout, or it may vary from one geographic location to another and from the top of the layer to the bottom. The percentages of clay and nonclay minerals may vary in the same manner.

PROPERTIES OF CLAY MINERALS

The plasticity, viscosity, shrinkage, swelling, and workability of each clay mineral are controlled by parameters such as crystal structure, particle size distribution, adsorbed exchangeable cations, soluble salts in the water surrounding the clay mineral particles, and the ability to adsorb

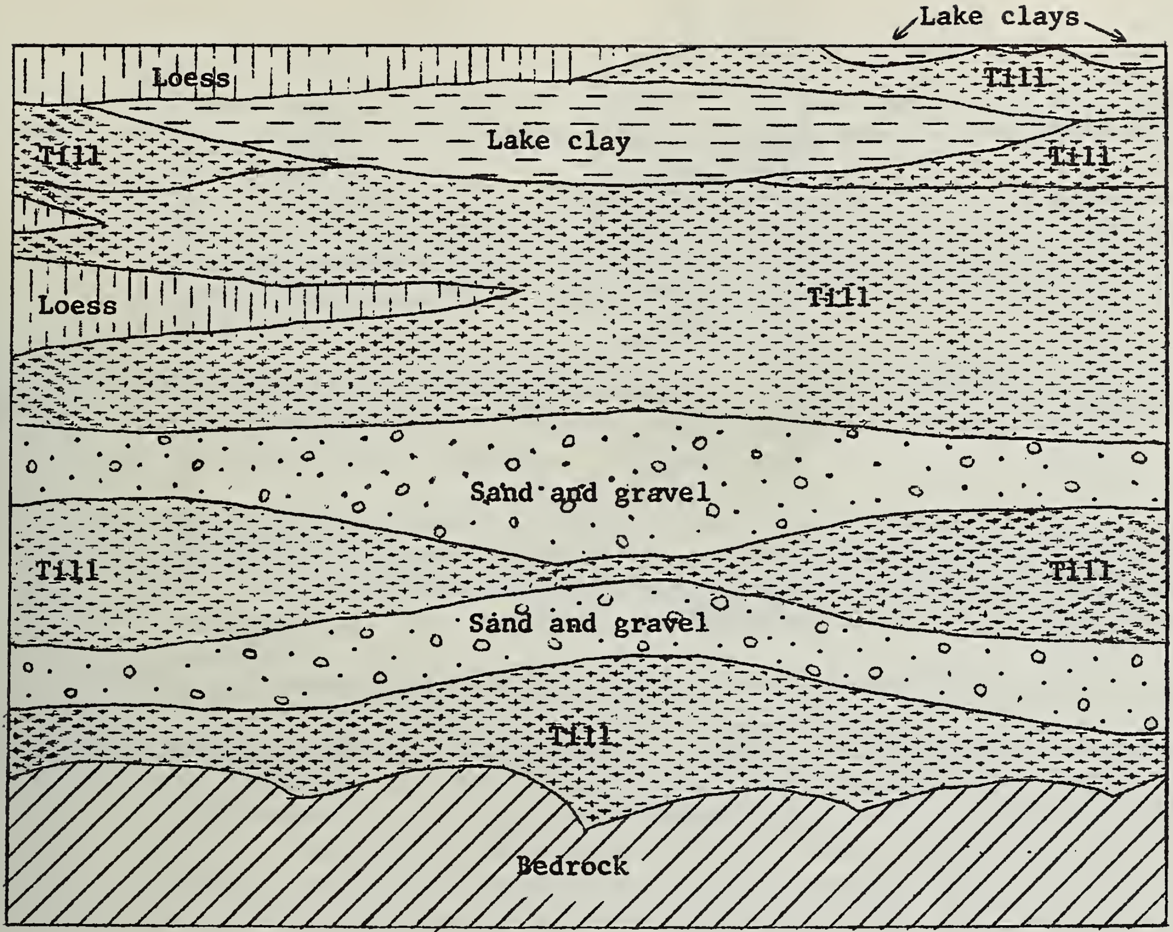

Fig. 1 - Schematic diagram showing typical layering of unconsolidated earth materials in Illinois (after White and Bremser, 1966).

certain organic molecules. The clay minerals exchange one cation for another in the same way that the compounds in water softeners soften hard water. Sodium in the softener is exchanged for calcium in the hard water, and calcium replaces the sodium in the softening compound. Each clay mineral has a specific arrangement of atoms (fig. 2) that is repeated to form the crystal structure, and each clay mineral will have at least one atom that makes it different from any other clay mineral.

If any one of these parameters is changed for the clay minerals, the properties of the earth material also will change. The farmer or gardener knows that if his soil is tight and hard he can lime the soil to increase its tilth. The tilth, which is the property of a soil that makes it loose and crumbly, is increased because the calcium of the lime replaces the hydrogen on the clay, which changes the properties of the clay minerals in the soil.

Clay, when mixed with water, becomes plastic; that is, it can be "worked" or formed into objects, such as the vase a potter forms on his wheel, that will retain their shapes. The plasticity of clay minerals has been studied at the Illinois Geological Survey for some time (Grim, 1941, 1942, 1948; White, 1949, 1954, 1958).

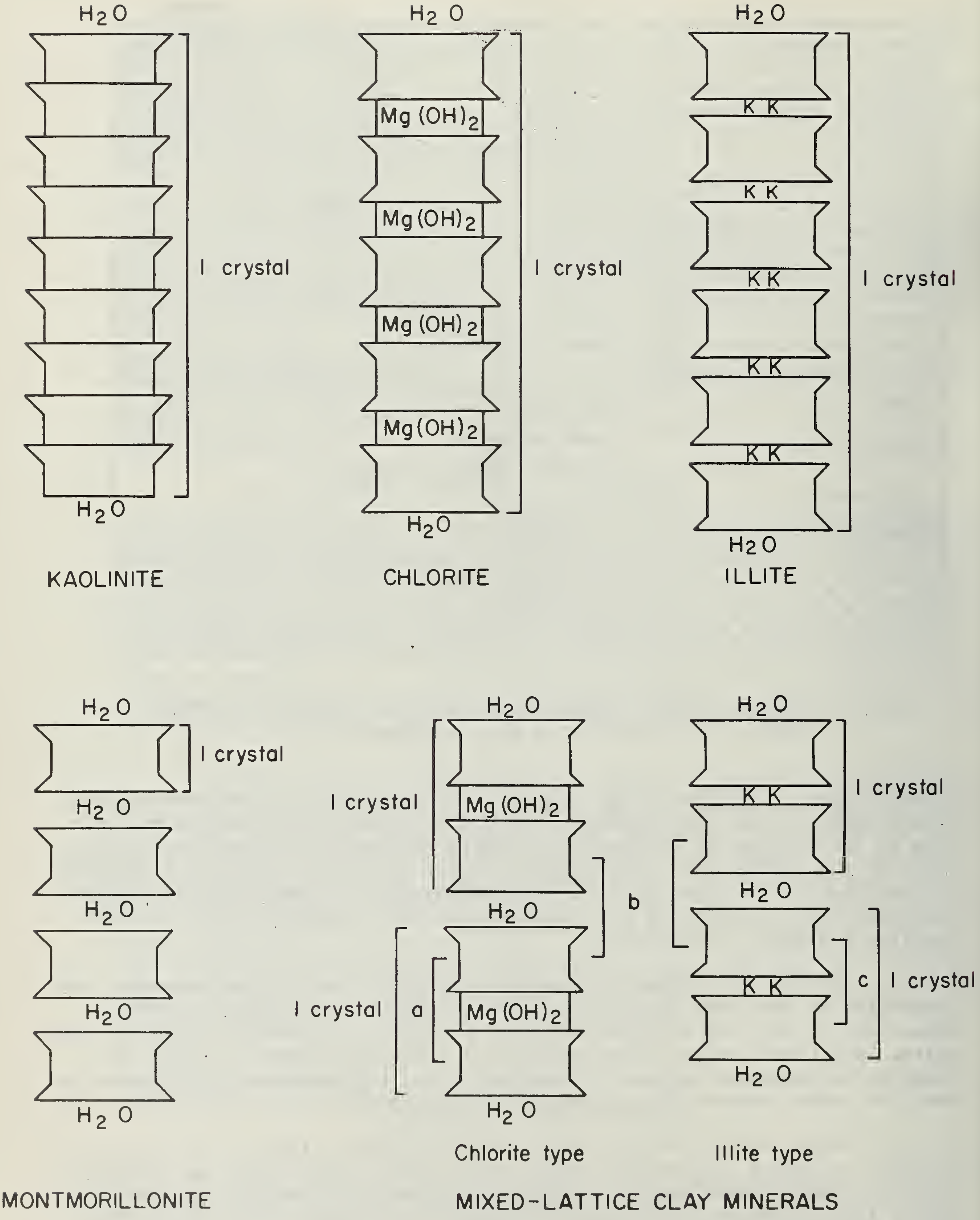

Fig. 2 - Schematic drawings of the structures of clay minerals showing how the basic cells are bonded together. H_2O = water; $Mg(OH)_2$ = brucite sheet; K = potassium; a = part of crystal that has the properties of chlorite; b = part of crystal that has the properties of montmorillonite; c = part of crystal that has the properties of illite.

Terms used in the study of clays, their plastic properties, and their moisture contents are defined below and their mutual relations given.

1) *The liquid limit.* The highest moisture content, expressed in percentage based on oven-dried clay, at which a clay can be formed into a small object that will retain its shape. At moisture contents higher than the liquid limit, the clay will flow under its own weight.

2) *The plastic limit.* The lowest percentage of moisture a clay can contain and still be shaped. With less moisture the clay will break or crumble during molding.

3) *The plasticity index* (sometimes called the plasticity range). The percentage difference between the liquid limit and the plastic limit. The higher the moisture content within the plasticity range, the lower the force required to shape the clay into a desired form.

(The three above indices are known as the Atterberg limits.)

4) *Activity value.* A value used to compare the plasticity ranges of clay minerals in earth materials without actually removing the nonclay substances from the earth materials. It is obtained by dividing the plasticity range of the natural earth material by the percentage of material it contains that is smaller than 2 microns. Multiplying the activity value by 100 gives the plasticity range of the clay minerals in the earth material.

5) *Natural water content.* The percentage of water in a saturated clay as it occurs naturally. Skempton (1953, p. 41) stressed its significance in relation to the Atterberg limits, and this relation is expressed by a liquidity index.

6) *Liquidity index* $= \dfrac{\text{natural water content - plastic limit}}{\text{liquid limit - plastic limit}}$ or

$$= \frac{\text{natural water content - plastic limit}}{\text{plasticity index}} .$$

When the natural water content and the liquid limit are the same, the liquidity index is 1.

If the introduction of a chemical, such as a detergent, into an earth material reduces the liquid limit, and hence also reduces the plasticity range, the liquidity index will become greater than 1. If, for example, a material had a natural water content of 60 percent, a liquid limit of 60 percent, and a plastic limit of 20 percent, the liquidity index would be

$$\frac{60 - 20}{60 - 20} = 1;$$

but if the liquid limit of this material were reduced to 40, the liquidity index would be

$$\frac{60 - 20}{40 - 20} = \frac{40}{20} = 2.$$

The clay would now be a quick clay that would flow under its own weight if disturbed; it would be very sensitive.

In most tills, the natural water content is below the liquid limit. If a till has a natural water content of 35 percent, a liquid limit of 45 percent, and a plastic limit of 25 percent, the liquidity index would be

$$\frac{35 - 25}{45 - 25} = \frac{10}{20} = 0.5.$$

If the liquid limit is reduced from 45 to 40, the liquidity index will increase from 0.5 to 0.67:

$$\frac{35 - 25}{40 - 25} = \frac{10}{15} = 0.67.$$

The lowering of the liquid limit and the increasing of the liquidity index suggest that the earth material, even when undisturbed, may be potentially more sensitive than the untreated material.

The earth material in both examples (first, the change of liquidity index from 1 to 2, and second, the change from 0.5 to 0.67) will be as strong after the introduction of the chemical as before, as long as it is not disturbed. However, if the clays are disturbed, the first will flow as a liquid, while the second will move a little more rapidly than it would have before the introduction of the chemical, provided a suitable force is being exerted upon it; the movement would probably be plastic in nature.

The plasticity range for montmorillonite is greater than that for illite, and the plasticity index for illite is greater than that for kaolinite. Chlorite has plastic properties similar to those of illite, and the mixed-layer clay minerals have plastic properties between those of illite and montmorillonite.

As the average particle size of each clay mineral decreases, its liquid limit and plasticity index increase, if all other variables are held constant. The exchangeable cation on the surface of the clay minerals also influences the plastic properties and water sorption properties when all other variables are held constant.

Rosenqvist (1955, p. 72) found that the plastic limit was affected little by the salinity of the water in the clay, but that the liquid limit and plasticity index could be changed considerably by changing that salinity. The exchangeable cations have little effect on the plastic limits of any clay mineral except montmorillonite, but the change for the liquid limit and plasticity index varies for each. There is little change for kaolinite but a large one for montmorillonite.

CLAY MATERIALS INVESTIGATED

The five clays used for the tests included one dominantly kaolinite, one that was mainly illite, one in which mixed-layer clay minerals predominated, and two montmorillonites, one from Mississippi and one from Wyoming.

The kaolinitic clay was from the Spoon Formation of the Pennsylvanian System. The sample was taken at the base of the Pennsylvanian in NW¼ SW¼ NW¼ sec. 10, T. 4 S., R. 5 W., Pike County, Illinois. It was about 80 percent kaolinite, 15 percent quartz, 2 percent titanium oxide, and 3 percent illite. About 80 percent of the clay was less than 2 microns, and the remaining 20 percent was larger.

The illitic clay sample came from an underclay below a coal in the Bond Formation of Pennsylvanian age at Fithian in W½ sec. 31, T. 19 N., R. 13 E., Vermilion County, Illinois. The clay minerals were illite and mixed-layer clay minerals. Thirty percent of the sample was less than 2 microns in size.

A sample from the Spoon Formation of Pennsylvanian age was taken from the Illinois Clay Products pit, sec. 11, T. 33 N., R. 8 E., Grundy County, Illinois. The clay was composed of mixed-layer clay minerals, illite, and about 10 percent kaolinite. Fifty percent of the sample was in the less-than-2-micron fraction.

The montmorillonite from Mississippi was Cretaceous in age and was furnished by International Minerals and Chemical Company, Skokie, Illinois. About 75 percent of the particles of this clay were less than 2 microns. Its cation exchange capacity was high, 93 me/100 gm; calcium was the exchangeable cation.

The montmorillonite from Wyoming also was of Cretaceous age and was obtained from the American Colloid Company, Skokie, Illinois. About 75 percent of the particles were less than 2 microns in size. Like the Mississippi clay, its cation exchange capacity was 93 me/100 gm, but in this clay sodium was the exchangeable cation.

METHODS

The study of the effects of waste effluents has been made in two parts. For the first phase, half of each illite, kaolinite, and mixed-layer clay sample was washed free of soluble salts and the clay-size fraction was removed from the sand and silty impurities in the clay. The clay-size fractions of the illitic, kaolinitic, and mixed-layer clays, and the two unpurified montmorillonitic clays were treated with various concentrations of a water softener, detergent, and soap. Results were reported by White and Bremser (1966). For this second part of the experiment, the remaining halves of the samples of illitic, kaolinitic, and mixed-layer clays and the two montmorillonitic clays were treated with various additives—water softeners, detergents, soap, fabric softener, and starch—without previous treatment.

The clay was first mixed thoroughly with water for $1\frac{1}{2}$ hours. Approximately 1500 ml water was used for 250 gm of the illitic, kaolinitic, and mixed-layer clays; for montmorillonites the proportions were 100 gm clay for 1500 ml water. The diluted additive was then mixed with the clay for 1 hour, following which the sample was allowed to dry at room temperature until its water content was near enough to the liquid limit to allow that test to be made. The plastic limit was then determined after further drying.

RESULTS OF INVESTIGATIONS

The plasticity and activity data for the clays tested are shown in tables 1 through 6. Table 1 contains the Atterberg limits for an untreated kaolinitic clay and for the same clay after treatment with water softeners, soap, fabric softener, starch, and various detergents. Tables 2 and 3 give the same data for illitic and mixed-layer clays, and tables 4 and 5 for two montmorillonitic clays. Table 6 contains the activity data for all the samples studied in tables 1 through 5. The data in these tables will not be discussed in detail in this report, but certain data are used as examples.

The first example (table 1) is a kaolinitic clay treated with sodium carbonate, which is used as a water softener in some detergents. Comparison of the plasticity indices, or ranges, of the untreated kaolinitic clay sample and those of the sample of the same clay that was treated with 0.2 percent sodium carbonate shows that the plasticity index in the treated portion has been reduced 12 percent, which is 50 percent of the original plasticity range (24%). If the natural moisture content of that clay were close to the liquid limit, addition of a small quantity of sodium carbonate could cause the clay to become quick, and, if the clay were vibrated by natural phenomenon or some man-made device, it would flow almost like water. If the natural moisture content of the clay is, for example, 30 percent, which is about the liquid limit of the clay treated with 0.2 percent sodium carbonate, the clay would be much weaker after water carrying sodium carbonate entered the clay than before. It therefore would be much more likely to fail after being saturated with fluids from septic tanks, oxidation ponds, landfills, and rain storms than before the septic tank or other disposal system had been constructed.

A second example is the montmorillonitic clay from Mississippi that was treated with sodium carbonate. When the plasticity ranges of the untreated and treated clays (table 4) are compared, the data suggest that additions of sodium carbonate increase the strength of the clay. The sodium carbonate from septic tanks or other sources would probably cause the clay to expand more when wet and contract more in drying, as the additive makes it capable of holding more water.

The third example is a kaolinitic clay treated with starch. Table 1 shows that starch had little effect on the plasticity of kaolinite. Therefore the stability probably would not be affected by fresh starch. However, we have not studied the effects of decay products of starch and other compounds, which are produced by bacterial action.

Most of the additives used in this report have had some effect on the plasticity of the clay samples tested. Some of these products are more effective than others. By comparing the data for the untreated clay, which occurs on the first line of each table, with the other data, one can see how much the various concentrations of each compound alter the plasticity of each clay, whether it increases or decreases the strength of the clay, and how much.

Some of the detergents caused a reduction of the surface tension of the water, which caused the clays to dry out much more rapidly than the same clays would have dried before treatment. This is probably an advantage where a septic tank is continually supplying water to the surrounding area. The anionic detergents used in this study lowered the surface tension more than the cationic detergents did, and the clays treated with anionic detergents dried more rapidly.

The results of this phase of the investigation dealing with the whole clay material were so similar to those found for the clay minerals in the first phase that it is evident that the earth materials will react to waste effluents in the same manner as their clay minerals.

The results of both phases of this study, along with water sorption data for both sets of samples, will be used in a future Geological Survey publication in which all the data will be discussed in much more detail.

DISCUSSION OF POSSIBLE CONDITIONS

Glacial tills contain illite, chlorite, kaolinite, mixed-structure clay minerals, and, in western Illinois, montmorillonite. They also contain fissures along which solutions can move, and the clay minerals along the surfaces of the fissures can react with chemicals in the solution. The clay minerals in the tills will have plastic properties similar to those of the clay minerals in the clays reported in tables 1, 2, 3, and 4. The tills would probably become sensitive when subjected to chemicals, as suggested earlier. The activity values would be similar to those in table 6.

Materials like loess and lake silts may allow water containing waste effluents to filter through to an impermeable layer such as till or shale and may even allow seepage along hillsides and bluffs, causing the slope to become quite unstable. Most of the loess deposits (Frye, Glass, and Willman, 1962) of the state, till deposits in western Illinois (Willman, Glass, and Frye, 1963), and Illinoian glacial lake and Cretaceous deposits of western Illinois (Frye, Willman, and Glass, 1964) may contain appreciable quantities of montmorillonite that has calcium as an exchangeable cation. White (1958, p. 23-26) showed that montmorillonite containing exchangeable calcium will adsorb water and swell, and that the same montmorillonite treated so that it contains sodium as the exchangeable cation will adsorb several times more water. The liquid limits and plasticity indices for the montmorillonite (table 4) in which the exchangeable cation is calcium increased as the concentrations of soap, water softeners, and commercial detergents were increased. The increase was probably brought about by the exchange of the sodium in the laundry preparations for the exchangeable calcium on the clay surface.

TABLE 1 - ATTERBERG LIMITS FOR KAOLINITE

Additives (% based on dry weight of clay)	Liquid limit (% water)	Plastic limit (% water)	Plasticity index (% water)
Untreated	44	20	24
Water softeners			
Sodium carbonate			
0.2	31	19	12
0.4	33	19	14
0.8	35	19	16
2.0	39	21	18
4.0	42	22	20
Sodium hexametaphosphate			
0.5	41	20	21
1.0	46	21	25
2.0	40	20	20
5.0	47	20	27
10.0	41	18	23
Soap			
0.2	44	22	22
0.4	40	21	19
1.0	44	21	23
2.0	43	21	22
4.0	43	22	21
Fabric softener			
0.4	38	21	17
2.0	43	20	23
4.0	44	21	23
Starch			
0.1	43	19	24
0.5	45	19	26
1.0	45	19	26
2.0	46	19	27
5.0	48	23	25
Detergents			
Commercial			
A.			
0.5	39	20	19
1.0	38	21	17
2.0	41	21	20
5.0	43	21	22
10.0	44	21	23
B.			
0.1	43	19	24
0.5	41	21	20
1.0	39	18	21
2.0	38	17	21
5.0	38	16	22

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TABLE 1 -- ATTERBERG LIMITS FOR KAOLINITE (Concluded)

Additives (% based on dry weight of clay)	Liquid limit (% water)	Plastic limit (% water)	Plasticity index (% water)
Detergents (continued)			
Nonionic			
0.1	37	21	16
0.5	35	19	16
1.0	39	21	18
2.0	41	21	20
5.0	51	22	29
Cationic			
A.			
0.06	37	21	16
0.32	42	21	21
0.60	41	21	20
1.24	44	20	24
B.			
0.06	36	22	14
0.32	41	23	18
0.60	39	24	15
1.24	42	23	20
Anionic			
A.			
0.04	34	19	15
0.16	34	20	14
0.32	36	20	16
0.60	36	21	15
B.			
0.04	38	21	17
0.20	38	22	16
0.36	36	23	13
0.72	37	23	14
C.			
0.04	40	19	21
0.20	37	20	17
0.40	36	20	16
0.80	36	20	16
D.			
0.04	37	21	16
0.20	37	23	14
0.40	36	22	14
0.80	35	23	12

TABLE 2 - ATTERBERG LIMITS FOR ILLITE FROM FITHIAN, ILLINOIS

Additives (% based on dry weight of clay)	Liquid limit (% water)	Plastic limit (% water)	Plasticity index (% water)
Untreated	48	26	22
Water softeners			
Sodium carbonate			
0.2	42	26	16
0.4	42	26	16
0.8	43	27	16
2.0	43	25	18
4.0	44	27	17
Sodium hexametaphosphate			
0.5	46	27	19
1.0	42	27	15
2.0	39	26	13
5.0	41	24	17
10.0	48	24	24
Soap			
0.2	50	28	22
0.4	50	27	23
1.0	49	28	21
2.0	53	27	26
4.0	57	28	29
Fabric softener			
0.4	45	28	17
2.0	48	27	21
4.0	50	27	23
Starch			
0.1	51	26	25
0.5	53	26	27
1.0	47	25	22
2.0	50	26	24
5.0	49	27	22
Detergents			
Commercial			
A.			
0.5	49	27	22
1.0	46	27	19
2.0	47	27	20
5.0	50	28	22
10.0	54	28	26
B.			
0.1	50	27	23
0.5	50	26	24
1.0	49	25	24
2.0	46	25	21
5.0	43	23	20

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TABLE 2 - ATTERBERG LIMITS FOR ILLITE FROM FITHIAN, ILLINOIS (Concluded)

Additives (% based on dry weight of clay)	Liquid limit (% water)	Plastic limit (% water)	Plasticity index (% water)
Detergents (continued)			
Nonionic			
0.1	48	27	21
0.5	45	25	20
1.0	47	26	21
2.0	52	28	24
5.0	48	27	21
Cationic			
A.			
0.06	43	25	18
0.32	46	26	20
0.60	47	27	20
1.24	50	28	22
B.			
0.06	43	27	16
0.32	45	29	16
0.60	43	28	15
1.24	44	29	15
Anionic			
A.			
0.04	45	28	17
0.16	39	26	13
0.32	41	26	15
0.60	42	27	15
B.			
0.04	42	26	16
0.20	42	26	16
0.36	41	27	14
0.72	46	26	20
C.			
0.04	41	26	15
0.20	43	26	17
0.40	41	25	16
0.80	42	27	15
D.			
0.04	41	25	16
0.20	43	28	15
0.40	44	28	16
0.80	43	27	16

TABLE 3 - ATTERBERG LIMITS FOR ILLITE FROM GRUNDY COUNTY, ILLINOIS

Additives (% based on dry weight of clay)	Liquid limit (% water)	Plastic limit (% water)	Plasticity index (% water)
Untreated	68	27	41
Water softeners			
Sodium carbonate			
0.2	66	28	38
0.4	68	28	40
0.8	69	26	43
2.0	72	27	45
4.0	78	32	46
Sodium hexametaphosphate			
0.5	68	28	40
1.0	65	28	37
2.0	67	26	41
5.0	69	26	43
10.0	68	26	42
Soap			
0.2	66	26	40
0.4	65	26	39
1.0	70	27	43
2.0	69	28	41
4.0	68	28	40
Fabric softener			
0.4	66	26	40
2.0	69	29	40
4.0	73	30	43
Starch			
0.1	72	25	47
0.5	73	27	46
1.0	74	26	48
2.0	75	25	50
5.0	75	28	47
Detergents			
Commercial			
A.			
0.5	67	27	40
1.0	67	26	41
2.0	66	28	38
5.0	71	28	43
10.0	77	28	49
B.			
0.1	72	26	46
0.5	67	28	39
1.0	68	28	40
2.0	72	28	44
5.0	78	24	54

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TABLE 3 - ATTERBERG LIMITS FOR ILLITE FROM GRUNDY COUNTY, ILLINOIS (Concluded)

Additives (% based on dry weight of clay)	Liquid limit (% water)	Plastic limit (% water)	Plasticity index (% water)
Detergents (continued)			
Nonionic			
0.1	71	27	44
0.5	70	30	40
1.0	70	27	43
2.0	74	27	47
5.0	83	31	52
Cationic			
A.			
0.06	65	27	38
0.32	64	30	34
0.60	71	35	36
1.24	66	34	32
B.			
0.06	63	29	34
0.32	64	32	32
0.60	66	32	34
1.24	68	35	33
Anionic			
A.			
0.04	64	27	37
0.16	63	29	34
0.32	63	29	34
0.60	63	30	33
B.			
0.04	64	28	36
0.20	63	29	34
0.36	66	30	36
0.72	62	28	34
C.			
0.04	64	28	36
0.20	68	29	39
0.40	67	30	37
0.80	64	27	37
D.			
0.04	63	29	34
0.20	64	30	34
0.40	66	30	36
0.80	70	32	38

TABLE 4 - ATTERBERG LIMITS FOR MONTMORILLONITE FROM MISSISSIPPI

Additives (% based on dry weight of clay)	Liquid limit (% water)	Plastic limit (% water)	Plasticity index (% water)
Untreated	147	46	101
Water softeners			
Sodium carbonate			
0.5	167	42	125
1.0	201	45	156
2.0	279	40	239
5.0	312	39	273
10.0	360	43	317
Sodium hexametaphosphate			
0.5	191	48	143
1.0	206	53	153
2.0	257	53	204
5.0	297	46	251
10.0	307	51	256
Soap			
0.5	184	45	139
1.0	184	48	136
2.5	224	48	176
5.0	244	50	194
10.0	246	52	194
Fabric softener			
1.0	171	46	125
5.0	161	44	117
10.0	150	50	100
Starch			
0.1	180	45	135
0.5	174	45	129
1.0	165	45	120
2.0	166	42	124
5.0	163	47	116
Detergents			
Commercial			
A.			
0.5	187	47	140
1.0	205	48	157
2.0	235	52	183
5.0	272	55	217
10.0	331	60	271
B.			
0.1	178	45	133
0.5	189	45	144
1.0	185	46	139
2.0	189	45	144
5.0	231	44	187

(Concluded on next page)

TABLE 4 - ATTERBERG LIMITS FOR MONTMORILLONITE FROM MISSISSIPPI (Concluded)

Additives (% based on dry weight of clay)	Liquid limit (% water)	Plastic limit (% water)	Plasticity index (% water)
Detergents (continued)			
Nonionic			
0.1	175	47	128
0.5	178	46	132
1.0	190	47	143
2.0	223	49	174
5.0	244	38	206
Cationic			
A.			
0.15	149	44	105
0.8	146	50	96
1.5	141	48	93
3.1	128	52	76
B.			
0.15	162	44	118
0.8	157	45	112
3.1	147	47	100
Anionic			
A.			
0.1	134	48	86
0.4	134	46	88
0.8	143	47	96
1.5	143	45	98
B.			
0.1	140	45	95
0.5	146	43	103
0.9	143	47	96
1.8	148	45	103
C.			
0.1	137	46	91
0.5	130	46	84
1.0	144	46	98
2.0	162	45	117
D.			
0.1	151	45	106
0.5	145	47	98
1.0	140	43	97
2.0	143	47	96

TABLE 5 - ATTERBERG LIMITS FOR MONTMORILLONITE FROM WYOMING

Additives (% based on dry weight of clay)	Liquid limit (% water)	Plastic limit (% water)	Plasticity index (% water)
Untreated	692	34	658
Water softeners			
Sodium carbonate			
0.5	678	27	651
1.0	657	30	627
2.0	636	35	601
5.0	623	43	580
10.0	633	42	591
Sodium hexametaphosphate			
0.5	573	36	537
1.0	560	37	523
2.0	529	39	490
5.0	515	39	476
10.0	461	40	421
Soap			
0.5	626	35	591
1.0	642	38	604
2.5	662	40	622
3.5	668	36	632
5.0	668	41	627
7.5	688	39	649
10.0	693	41	652
Fabric softener			
1.0	626	37	589
5.0	595	31	564
10.0	582	39	543
Starch			
0.1	708	35	673
0.5	689	31	658
1.0	680	34	646
2.0	693	36	657
5.0	723	39	684
Detergents			
Commercial			
A.			
0.5	609	34	575
1.0	596	35	561
2.0	594	38	556
5.0	577	38	539
10.0	566	46	520
B.			
0.1	682	34	648
0.5	688	37	651
1.0	699	35	664
2.0	682	35	647
5.0	684	30	654

(Concluded on next page)

TABLE 5 - ATTERBERG LIMITS FOR MONTMORILLONITE FROM WYOMING (Concluded)

Additives (% based on dry weight of clay)	Plastic limit (% water)	Plastic limit (% water)	Plasticity index (% water)
Detergents (continued)			
Nonionic			
0.1	653	43	610
0.5	634	40	594
1.0	635	39	596
2.0	641	40	601
5.0	637	41	596
Cationic			
A.			
0.15	549	33	516
0.8	544	32	512
1.5	548	35	513
3.1	502	32	470
B.			
0.15	577	36	541
0.8	592	33	559
1.5	665	39	626
3.1	670	37	633
Anionic			
A.			
0.1	592	32	560
0.4	579	31	548
0.8	585	34	551
1.5	593	35	558
B.			
0.1	523	31	492
0.5	555	32	523
0.9	564	32	532
1.8	533	37	496
C.			
0.1	527	32	495
0.5	588	36	552
1.0	603	39	564
2.0	628	37	591
D.			
0.1	602	35	567
0.5	593	34	559
1.0	630	34	596
2.0	584	33	551

TABLE 6 - ACTIVITY VALUES FOR CLAY MATERIALS

Additives (% based on 250 grams of clay)	Kaolinite	Illite from Fithian	Illite from Grundy County
Untreated	0.30	0.73	0.82
Water softeners			
Sodium carbonate			
0.2	0.15	0.53	0.76
0.4	0.18	0.53	0.80
0.8	0.20	0.53	0.86
2.0	0.23	0.60	0.90
4.0	0.25	0.57	0.92
Sodium hexametaphosphate			
0.5	0.26	0.63	0.80
1.0	0.31	0.50	0.74
2.0	0.25	0.43	0.82
5.0	0.34	0.57	0.86
10.0	0.29	0.80	0.84
Soap			
0.2	0.28	0.73	0.80
0.4	0.24	0.77	0.78
1.0	0.29	0.70	0.86
2.0	0.28	0.87	0.82
4.0	0.26	0.97	0.80
Fabric softener			
0.4	0.21	0.57	0.80
2.0	0.29	0.70	0.80
4.0	0.29	0.97	0.86
Starch			
0.1	0.30	0.83	0.94
0.5	0.33	0.90	0.92
1.0	0.33	0.73	0.96
2.0	0.34	0.80	1.00
5.0	0.31	0.73	0.94
Detergents			
Commercial			
A.			
0.5	0.24	0.73	0.80
1.0	0.21	0.63	0.82
2.0	0.25	0.67	0.76
5.0	0.28	0.73	0.86
10.0	0.29	0.87	0.98

Additives (% based on 100 grams of clay)	Montmorillonite from Mississippi	Montmorillonite from Wyoming
Untreated	1.35	8.77
Water softeners		
Sodium carbonate		
0.5	1.67	8.68
1.0	2.08	8.26
2.0	3.19	8.01
5.0	3.64	7.73
10.0	4.23	7.88
Sodium hexametaphosphate		
0.5	1.91	7.16
1.0	2.04	6.97
2.0	2.72	6.53
5.0	3.35	6.35
10.0	3.61	5.61
Soap		
0.5	1.85	7.88
1.0	1.81	8.05
2.5	2.35	8.29
3.5		8.43
5.0	2.59	8.36
7.5		8.65
10.0	2.59	8.69
Fabric softener		
1.0	1.67	7.85
5.0	1.56	7.52
10.0	1.33	7.24
Starch		
0.1	1.80	8.97
0.5	1.72	8.77
1.0	1.60	8.61
2.0	1.79	8.76
5.0	1.55	9.12
Detergents		
Commercial		
A.		
0.5	1.87	7.67
1.0	2.09	7.48
2.0	2.44	7.41
5.0	2.89	7.19
10.0	3.61	6.93

(Concluded on next page)

TABLE 6 - ACTIVITY VALUES FOR CLAY MATERIALS (Concluded)

Additives (% based on 250 grams of clay)	Kao-linite	Illite from Fithian	Illite from Grundy County	Additives (% based on 100 grams of clay)	Montmo-rillonite from Mis-sissippi	Montmo-rillonite from Wyoming
Detergents (continued)				Detergents (continued)		
B.				B.		
0.1	0.30	0.77	0.92	1.0	1.77	8.64
0.5	0.25	0.80	0.78	0.5	1.92	8.68
1.0	0.26	0.80	0.80	1.0	1.83	8.85
2.0	0.26	0.70	0.88	2.0	1.92	8.63
5.0	0.28	0.67	1.08	5.0	2.49	8.72
Nonionic				Nonionic		
0.1	0.20	0.70	0.88	0.1	1.71	8.13
0.5	0.20	0.67	0.80	0.5	1.76	7.92
1.0	0.23	0.70	0.86	1.0	1.91	7.95
2.0	0.20	0.80	0.94	2.0	2.32	8.01
5.0	0.37	0.70	1.04	5.0	2.75	7.95
Cationic				Cationic		
A.				A.		
0.06	0.20	0.60	0.76	0.15	1.40	6.88
0.32	0.26	0.67	0.68	0.8	1.28	6.83
0.60	0.25	0.67	0.72	1.5	1.24	6.84
1.24	0.30	0.73	0.64	3.1	1.01	6.27
B.				B.		
0.06	0.18	0.53	0.68	0.15	1.57	7.21
0.32	0.23	0.53	0.64	0.8	1.49	7.45
0.60	0.19	0.50	0.68	1.5		8.35
1.24	0.25	0.50	0.66	3.1	1.33	8.44
Anionic				Anionic		
A.				A.		
0.04	0.19	0.57	0.74	0.1	1.15	7.47
0.16	0.18	0.43	0.68	0.4	1.17	7.31
0.32	0.20	0.50	0.68	0.8	1.28	7.35
0.60	0.19	0.50	0.66	1.5	1.31	7.44
B.				B.		
0.04	0.21	0.53	0.72	0.1	1.27	7.89
0.20	0.20	0.53	0.68	0.5	1.37	6.97
0.36	0.16	0.47	0.72	0.9	1.28	7.09
0.72	0.18	0.67	0.68	1.8	1.37	6.61
C.				C.		
0.04	0.26	0.50	0.72	0.1	1.21	6.60
0.20	0.21	0.57	0.78	0.5	1.12	7.36
0.40	0.20	0.53	0.74	1.0	1.31	7.52
0.80	0.20	0.50	0.74	2.0	1.56	7.88
D.				D.		
0.04	0.20	0.53	0.68	0.1	1.41	7.56
0.20	0.18	0.50	0.68	0.5	1.31	7.45
0.40	0.18	0.53	0.72	1.0	1.29	7.92
0.80	0.15	0.53	0.76	2.0	1.28	7.35

If septic tank fields or other refuse disposal sites are placed in loess anywhere in Illinois, or in till, glacial lake and Cretaceous deposits in western Illinois, the exchange of sodium for calcium in these deposits could increase the differential shrinkage during drouth and swelling during wet periods. After a period of time, damage to foundations of buildings, sidewalks, and streets could result.

SUMMARY

Deposits of earth materials that are normally stable may be significantly affected when saturated with effluents from septic tanks, oxidation ponds, refuse sites, and landfills. In potential industrial and residential developments where waste materials are to be disposed of by such methods, it is essential for developers, architects, contractors, home owners, and business men to be aware that some earth materials may become unstable when exposed to effluents from these installations. When such developments are planned, soils should be tested to determine whether they would remain stable under the existing topographic and geologic conditions after being saturated for a period of time with waste effluents.

The natural moisture content, the amount of clay in the earth materials, the clay minerals present, the plasticity indices of the earth materials the topography and drainage, and the geology of the area should all be known to the developer of an area.

In areas where the earth materials contain montmorillonite with calcium as the exchangeable cation, the effluents may increase the swelling by exchanging their sodium for the exchangeable calcium on the clay. Considerable movement can occur as the result of swelling of the clay during the wet season and shrinkage during the dry season, and such changes should be considered when foundations and buildings are designed.

Some anionic detergents reduce the surface tension of water, which accelerates the normal rate of evaporation. This property can be advantageous for septic systems, particularly in wet weather.

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